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ECL 246

TIP TANKS FOR THE BEECH SUPER KING AIR

To increase the range of a twin engine airplane, extra fuel tanks must be designed and integrated with other sytems. The project involves activities ranging from drafting and cost estimation, to vibration testing and lightning strike tests. Doug Marwill and two other engineers at Beechcraft spend about a year on the modification; they deal with vendors and subcontractors, as well as with the Federal Aviation Administration.

Prepared by R. D. Marwill at Wichita State University
under the supervision of J. A. Alic.

TIP TANKS FOR THE BEECH

SUPER KING AIR

Part A

The Tank Design

Beech Aircraft Corporation, with headquarters in Wichita, Kansas, is one of the world's largest producers of general aviation aircraft. The company was founded in 1932 by Mr. and Mrs. Walter H. Beech. After the death of Walter Beech in 1950, Mrs. O. A. Beech became President and is still active in the company today as Chairman of the Board of Directors.

Beech Aircraft is known worldwide as a manufacturer of superior quality aircraft beginning with a two place single engine plane up to the twin turboprop, 15 passenger Super King Air Model 200. Today the company employs more than 8,000 people with sales totalling more than $400,000,000 annually.

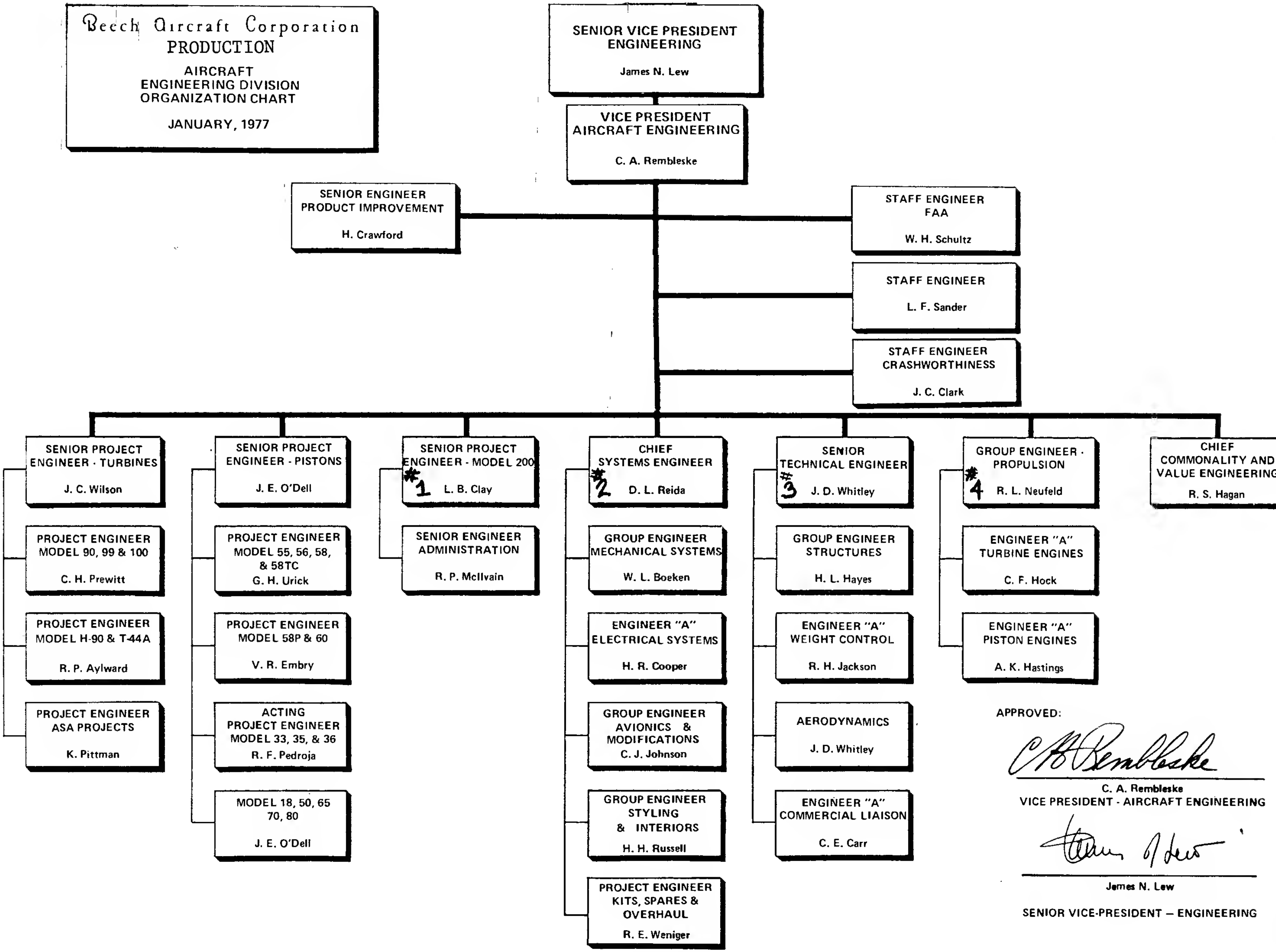
The Model 200 Super King Air is one of the most successful selling aircraft Beech has ever built. Three hundred of these top-of-the-line aircraft have been built in approximately three years. This is an impressive production record for an aircraft whose average cost is over $1 million each. This aircraft is now one of the most popular Beech models and a continuous backlog of orders remains as new applications for its use continue to grow. In 1975, one of these new applications arose when a customer asked for an aircraft which could fly 2300 nautical miles without refueling. The most economical solution to the requirement appeared to be the addition of fuel tanks on the wing tips of a Model 200. But as Doug Marwill and Gene Nusz, two design engineers in the Propulsion Systems Group, were to find out, it would be a busy 12-month project with some challenging design hurdles.

The basic Model 200, Exhibit A-1, is an 8 to 15 passenger pressurized all-weather turboprop transport aircraft which was introduced in December, 1973. Its maximum range at standard day conditions and 31,000 ft. altitude is 1887 nautical miles (nm). The proposed extended range turboprop Model 200T was to be identical to the basic Model 200 except for a stronger wing designed to carry a 52 gallon fuel tank on each wing tip. This extra 104 gallons of fuel would be required to extend the aircraft's flying distance another 445 nm.

Doug Marwill pointed out, "A project of this nature requires support from almost every engineering group in the Production Engineering Division." At Beech, the Aircraft Engineering Department is divided into two divisions: Research and Development, and Production Engineering. For this particular project, the Production Engineering Division was to design, develop and FAA certify the wing tip tank design. The organization chart, Exhibit A-2, shows the breakdown of the groups within the Production Engineering Division.

EXHIBIT A-1

Beechcraft Super King Air



APPROVED:

C. A. Rembleske
VICE PRESIDENT - AIRCRAFT ENGINEERING

James N. Lew
SENIOR VICE-PRESIDENT – ENGINEERING

EXHIBIT A-2

ECL 246A

The Model 200 project group (Block 1 in Exhibit A-2) is responsible for coordinating all the engineering efforts of the other groups involved in this tip tank design project. Mr. L. B. Clay, the project engineer for this program, had the job of coordinating the efforts of the support engineering groups to keep the project on schedule and to resolve major design problems as they occurred.

One of these support groups is the Systems Engineering group (Block 2) which itself includes several subgroups. One of these subgroups is the Mechanical Systems group which is responsible for all environmental systems, cockpit control systems, anti-icing systems, flight control and landing gear systems. A second subgroup within Systems Engineering is the Electrical Engineering group which is responsible for all aircraft electrical design except avionics (airborne electronics). Avionics is consolidated into another subgroup. Still another subgroup is Styling and Interiors. Their task is to design the cabin interior equipment and arrangement which will best suit the customer's needs. This includes everything from seats, ashtrays and liquor bars to cargo handling equipment or camera installations for terrain mapping.

Another major group is Technical Engineering (Block 3), consisting of Structures, Weight Control and Aerodynamics. The Structures subgroup is responsible for ensuring adequate strength levels in the aircraft structure. They are responsible for seeing that any changes and modifications have adequate structural strength and do not adversely effect the safety of the aircraft. This subgroup does not design aircraft structure but only provides analytical support for other groups. The Weight Control subgroup is responsible for monitoring the effects of changes or modifications on the aircraft's total weight and its overall balance. The Aerodynamics subgroup must provide predicted flight characteristics due to changes or modifications to the aircraft.

The last group shown in Exhibit A-2 is Propulsion Systems (Block 4), which is composed of the Turbine Engine group and Piston Engine group. This group has the responsibility for design of the fuel systems and engine installations on all Beech aircraft. In this particular project, the Turbine Engine group, where Doug Marwill and Gene Nusz worked, was given the responsibility for the design of the wing tip tank and its operation in conjunction with the aircraft's main fuel system.

Doug Marwill had joined Beech Aircraft as a design engineer in 1969 and had been assigned to the Production Engineering Turbine Propulsion Systems group since that time. Gene Nusz had been assigned to the Propulsion Systems group in Research and Development until 1973. At that time, he joined the Production Propulsion Systems group, working mainly on the newly FAA certified Model 200.

The tip tank project began in October, 1975, when a prospective customer approached Beech Aircraft with the idea of building a special purpose aircraft to be used for aerial photography. The most difficult specification was that the aircraft be able to stay airborne for at least 11 hours. Engineering was asked to determine if it was feasible to stretch the Model 200's flying time from 9.5 hours to 11 hours. The first concern was to determine how many gallons of fuel would be required to fly for 11 hours.

Doug said, "Engine fuel consumption rates are given as lbs/hr/hp. From previous flight testing, we knew how much fuel was required for taxi, takeoff, climb, cruise, and descent. But the length of time to perform these maneuvers is a function of aircraft weight. Therefore, we first had to know the new weight of the aircraft! This was a problem since weight cannot be calculated until fuel quantity is known and fuel quantity, determined by fuel consumption, cannot be found until aircraft weight is known. Fortunately, it is easy to use trial and error for such a problem, since we know that it takes a pretty big change in weight to have much effect on the fuel consumption." Taking previous cruise fuel consumption rates at an aircraft gross weight of 12,500 lb and assuming a new aircraft weight of 13,500 lb at takeoff, Doug found the total flying time required 3,585 lb of fuel (560 gallons) when the aircraft was at 25,000 ft under standard day conditions. Previous test data indicated this gross weight would require 95 lb of fuel for taxi and takeoff, 230 lb for climb, 165 lb for descent and 270 lb for emergency reserve. This gave a total of 4,345 lb (650 gallons) of fuel for an 11 hour mission. The zero-fuel weight of the aircraft, including all special mission equipment, was 9,250 lb. This gave a total weight of 13,595 lb with fuel, minus 95 lb for taxiing, leaving 13,500 lb gross weight at lift-off. Doug said, "Several iterations are often required to find the correct combination of weight and fuel consumption before total fuel quantity required can be determined." After finishing his calculations, Doug found that 104 gallons of additional fuel would be required.

Doug said, "The next question to be answered was where to put the 104 gallons of fuel! Two possibilities had been talked about. The first suggestion was to put all of the additional fuel in one tank inside the fuselage. This idea was an economical one from a cost and time standpoint because it required little modification to the aircraft. But it had some serious disadvantages. First of all, it is dangerous to store fuel in a passenger compartment. Second, it occupied valuable space required by the customer's mission equipment. And third, it presented a center of gravity balance problem for the aircraft.

"The other proposal was to build a fuel tank mounted on the external surface of the wing tip," he continued. "The advantages were that it did not increase the wing fatigue bending moment in flight because it would be located on that portion of the wing which was flying or supporting itself. It also did not occupy usable cabin space and could easily be lengthened in the future to gain additional fuel. This aspect seemed favorable from the standpoint of future sales."

"However, this proposal also had some drawbacks. The modification would require strengthening of the wing to support the additional dynamic loads on the wing during landings caused by the added weight at the wing tip. Flight testing would be needed to determine what effect the tip tanks would have on aircraft performance. And we would have to worry about protecting the tip tanks from lightning strikes, which usually occur on the nose, tail or wing tips of an aircraft."

The wing tip tank proposal was chosen by Engineering management because it appeared to be most promising for future use on other special mission aircraft, as well as other models in the Beech line. This decision by Engineering was sent to the Marketing Department within two weeks and presented to the potential customer for his evaluation. A few days later, a formal "Model Specification" was submitted to the potential customer providing essential predicted aircraft performance data. Excerpts from the Model Specification are given in Exhibit A-3. This specification gave data on the approximate size and location of the tanks, their usable fuel quantity, fuel systems operation, and fuel gauging system. Other information such as optional equipment, special equipment and special modifications were also listed in the Model Specification.

Several weeks passed before Beech was again contacted by the potential customer. At this time, the customer indicated approval of the proposal and asked for a price on the aircraft as specified in the Model Specification. This occurred in December, 1975, and was the real beginning of the project for Doug and Gene. It was at this point that Doug was asked to "bid" the job of designing a 52 gallon fuel tip tank for the Model 200T, as the new model was to be designated. Doug said, "The term 'bid' means that an engineer is given the job of looking at the project and deciding how it will be done. At this point, I looked at the project for any major problems in the system design or operation. Minor problems and exact details are not evaluated at this time."

"Manufacturers of major subassemblies and system components such as fuel quantity measuring systems, electrical components, fuel valves, etc., were contacted to help determine the feasibility of the proposed project," Doug went on. "The Federal Aviation Administration (FAA) was formally contacted by letter and asked to determine what regulations would apply to this modification. Also, since this customer was from France, the French equivalent to our FAA was contacted to determine if they had any special regulations on this class of aircraft."

Doug said, "The first major task was compliance with FAA regulations. In the United States, all fixed wing aircraft are basically divided into two classifications determined by gross weight. All aircraft manufactured by Beech Aircraft and most other general aviation companies are under 12,500 lb, the arbitrary dividing point established by the FAA. If an aircraft exceeds this weight, it must conform to a completely different set of regulations. Since the Model 200T was going to have a gross weight of 13,595 lbs, we had to find a means of staying legal so the rules for aircraft under 12,500 lb would still apply. We decided to design tip tanks which could be removed by the customer. With the tanks removed, the 200T could operate normally as an

Beechcraft **Model Specification**

BS 22780
October 24, 1975
Page 1
Revised March 5, 1976

BEECHCRAFT SUPER KING AIR
PRESSURIZED TURBOPROP EXECUTIVE TRANSPORT
CAMERA/WING TIP FUEL TANK MODIFICATION

1. SCOPE

1.1 Model Designation. This specification establishes the requirements for the following aircraft:

Model Designation:	BEECHCRAFT Super King Air - Model 200
Crew:	Pilot, Nav-sight operator (copilot), and two camera operators.
Passengers: (Cameras Removed)	Four (FAA certified up to fifteen occupants).
Engines:	Two PT6A-41 free shaft turbine. Pratt & Whitney Aircraft of Canada, Ltd.
Propellers:	Two Hartzell 3-blade, full feathering, reversing, 98.5" diameter
Flight Controls:	Dual, side by side.
Construction:	All metal.
Landing Gear:	Retractable tricycle with dual main wheels (high flotation type).

1.2 General Description. This aircraft is a pressurized, high performance, all weather turboprop transport modified for photographic missions with alternate missions of personnel or cargo transport (if desired). Basic changes from the Commercial Standard Super 200 consist of removal of the six standard passenger chairs in the cabin and installing provisions for two tandem camera installations. Removable wing tip fuel tanks are also installed to provide the capability of increased range. When extended range is not required, a modified standard wing tip can be installed to convert the aircraft back to a commercial standard wing configuration.

2.0 Three View

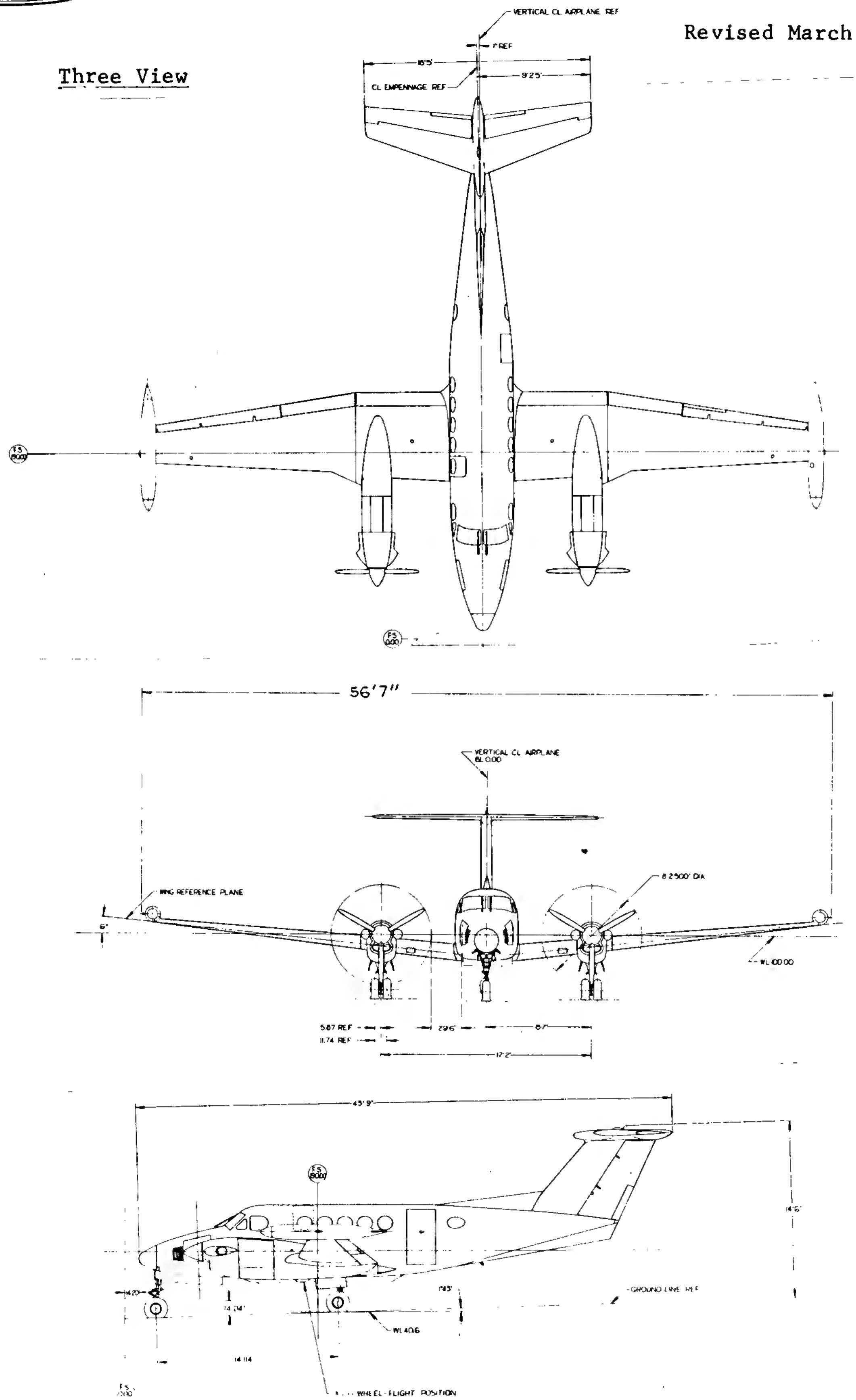


EXHIBIT A-3 (cont.)

4.0 Tabulated Performance. The following performance values are for zero wind, ICAO standard atmosphere and at a takeoff gross weight of 13,500 pounds unless otherwise noted. Engine data is based on UACL Specification No. 723 for the PT6A-41 engine. Engine performance is calculated with the UACL supplied basic computer program 1518B together with basic PT6 Tables 010 and the specific Tables 086 dated July 5, 1973.

*Speed using maximum cruise power (1900 RPM) at an average cruise weight of 11,500 pounds
at 25,000 feet . . . . 257 knots
*Speed for Max. range @ 25,000 ft. . . . . 209 knots
*Speed for Max. endurance @ 25,000 ft. . . . . 175 knots
Rate of climb at sea level (two engines) . . . . 2116 fpm
Rate of climb at sea level (one engine) . . . . 490 fpm
Rate of climb at 5,000 feet (one engine)
ISA + 22° . . . . 278 fpm
Service ceiling - two engines (100 fpm) . . . 28,400 ft
Service ceiling - one engine (50 fpm) . . . 12,700 ft

Stalling speed, power off:
Gear and flaps down . . . . 81 knots (93 mph)
Gear and flaps up . . . . 105 knots (121 mph)

Takeoff distance, normal procedure (40% flaps) hard surface:
Ground run . . . . 2061 ft
Total over 50-foot obstacle . . . . 2969 ft

Landing distance, full flaps, normal procedure, hard surface (without reverse)
Approach speed (Flaps 100%) . . . . 106 knots (122 mph)
Ground Run . . . . 1835 ft
Total over 50-foot obstacle . . . . 3058 ft

Range and Endurance @ 25,000 ft.	Configuration I 12,590 Pounds Ramp Weight 3645# Total Fuel	Configuration IV 13,671 Pounds Ramp Weight 4348# Total Fuel
Max. Cruise Power		
Range	1394 N.M.	1690 N.M.
True Airspeed	260 knots	257 knots
Endurance @ Altutide	4.84 hours	6.00 hours
Total	5.46 hours	6.67 hours
Max. Range Power		
Range	1610 N.M.	1901 N.M.
True Airspeed	205 knots	209 knots
Endurance @ Altitude	7.19 hours	8.39 hours
Total	7.81 hours	9.06 hours
Max. Endurance Power (Power to achieve 1.2 V_{S1})		
Range	1575 N.M.	1881 N.M.
True Airspeed	169 knots	175 knots
Endurance @ Altitude	8.53 hours	9.92 hours
Total	9.15 hours	10.59 hours

*At 11,500 lbs.

7.0 Propulsion - Tip Tank Details. For Structural Arrangement Drawing, see Page 4. The wing tip fuel tank is to be approximately 52.5 gal. capacity (usable fuel). Total tank length is to be approximately 118 inches with an approximate diameter of 15 inches in the center. The tank will be removable and attached in such a way that it can be removed with an expenditure of a reasonable number of manhours. There will be no jettisoning mechanism, release, or fuel dump system provided.

The outer wing panel tip is to be redesigned to provide attachment of the tip tank. The structure shall be capable of carrying static and dynamic landing and flight loads with the tip tanks attached. The outer wing panel tip outboard of W.S. 319 rib is to be redesigned (outboard aileron hinge attachment to be retained). Wing Station 319 rib, the main and rear spar caps and webs, and the skin covering are to be beefed up from station 319 to approximately 30 inches inboard. The main spar beefup is to continue inboard another 95 inches. A fairing will be added along the upper surface of the wing to fair the tip tank into the wing tip. With the tip tank removed, a modified standard tip shall be installed to restore the wing to a standard configuration.

The tip tank is to be attached to the wing tip in such a manner that the lower surface of the constant diameter cylinder section fairs smoothly into the lower surface of the wing (see 3-view). This will provide gravity drain capability for the tip tank fuel to drain into the outer panel fuel tank. An anti-siphon fuel filler cap will be included as a part of the tip tank design. This will allow fuel to be loaded to the standard Model 200 capacity of 544 gals. or the increased capacity of 649 gals. Expansion space for both the main fuel tanks and the tip tanks will be provided in the tip tank. Plumbing lines (drain and vent) will be installed to connect the tip tank into the outboard fuel tank rib (approximately 30 inches in length).

A fuel level transmitter and wire harness will be installed in each tip tank. A dual fuel quantity indicator will be added to the cockpit fuel panel to gauge the tip tank fuel. This indicator will show only the tip tank fuel quantity and will be independent of the standard fuel gauging system.

Strobe lights and wing position lights are to be installed in the nose cone of the tip tank. The flux valve for the remote compass will be removed from the wing tip and installed in the horizontal stabilizer.

aircraft with gross weight less than 12,500 lb. To perform its special mission of photographing land areas, a special permit was obtained to operate the aircraft over 12,500 lb with a limited crew and equipment on board. At this point, the customer specified that installation or removal of each tip tank should take 4 hours or less. Therefore, the design had to allow for quick conversion from one configuration to the other with no possibility of dangerous mistakes occurring."

Doug said, "The next important consideration was how to build the tip tank economically. Our customer only wanted four aircraft. Gene and I realized that this one customer would have to pay for the whole design package because this modification might never be sold again. So low cost was important."

One day while Gene and his boss, Cal Hock, were discussing the tip tank proposal, another engineer in a different design group overheard their discussion. He said he knew a former Beech employee who had started his own aluminum fabrication company in Wichita and was making target missiles and fuel tanks for other companies. Doug said, "We all discussed the possibility that maybe we could utilize this company's existing tooling to build the tip tanks we needed. I made a phone call and arranged a visit to this company, Globe Engineering."

The next day Doug, Gene and Cal visited Globe Engineering in Wichita and toured their facility. "We were lucky enough to find a tank which was ideal, except its capacity was about half of what was required," Doug recalled. The shape and diameter were perfect but it was too short. However, we thought a straight cylindrical section could be made to sandwich in between the existing nose section and tail section. The three men examined the construction of the tank and made sketches for later stress analysis.

Later that afternoon, after returning to the Beech Plant, it was decided to subcontract fabrication of the complete tip tank assembly to Globe Engineering. This new tank would be designed by Doug and Gene utilizing the existing nose and tail sections with a specially designed center section. This would save much time and cost on the project.

Doug said, "Another problem we had to consider was lightning protection for the tip tanks. Lightning strikes to aircraft in flight are not uncommon, though usually there's little or no damage. Typically, the lightning will strike the nose, the tail, or the wing tip and travel through the structure, exiting the opposite end or wing tip. I went to the Beech Engineering Library and spent several days reading up on lightning protection for aircraft. I found that a lot of government funded research data existed and that accepted design information such as tank wall thickness, lightning diverters and lightning transfer strips was available and not patented. This was important as many lightning protection devices are patented and can only be used after paying a substantial fee. We then decided that this information on design techniques for lightning protection would be used, but since Beech had never built tip tanks before, a full-fledged lightning test would be performed on the tip tank and outer wing section."

"Another consideration during this proposal analysis," Doug related, "was the elevation of the tip tank relative to the wing: Should the tip tank be above the wing, mid-wing or below the wing tip? This was important because of different advantages seen by each design group. The Aerodynamics group said the tank would work as a fence and give added lift if it was positioned below the wing tip. The Marketing group felt the aircraft would look better if the tanks were mounted half above and half below the wing tips. We in the Propulsion Systems group pointed out that the cost of installation would be the least if the tanks were mounted above the wing. If the tanks were mounted in this position, the fuel would gravity feed into the main tanks without the use of electric pumps or compressed air. Since cost was a significant factor in this design and a compromise in wing lift was not of a significant magnitude, the various Engineering group leaders decided to mount the tank above the wing. At this point, sketches of the aircraft with the tip tanks above the wing were made by the Art Department and shown to Marketing. After seeing the sketches, Marketing was convinced we had a good design which had a lot of eye appeal."

"The last major decision to make before submittal to the prospective customer was how to measure the total fuel capacity in the aircraft. The differentiating factor, of course, was cost." Doug's first idea was to <u>not</u> gauge the additional 52 gallons of fuel on each wing tip. This meant the existing fuel gauging system would remain unchanged and would begin showing fuel depletion after 52 gallons in the tip tanks had been used. Obviously, this was the least expensive design.

An alternative was proposed by Doug's supervisor. This was to install a secondary fuel gauging system to measure only fuel quantity in the tip tanks. The existing gauging system in the aircraft would remain unchanged.

The customer made a third proposal. They felt it would be desirable to have just one fuel gauging system measuring total fuel on the aircraft at all times. Doug said, "This was certainly feasible since the only factor was cost. Marketing suggested that we let the customer decide what he wanted to pay for and how much. Therefore, I spent the next three days preparing cost proposals for the three configurations.

"The Engineering Cost Proposal," Doug said, "is the difficult part of a project this size. Fortunately, I had already been making mental notes on the time required to do many of the smaller design jobs. However, I was a bit uneasy about bidding a job this big because of my past track record. Since 1970 I had bid about 30 cost proposals and many of them required more time than I had estimated. The customer is given a fixed cost, and if it's low, the company absorbs the loss. Two years ago, I began following up on my cost proposals by checking with the Cost Accounting group, who keeps records on engineering time spent on all projects. I used the information they gave me to find a fudge factor to correct for underbidding. Then I bid the jobs as before but increased the total hours by 20%. This has brought the number of hours bid and the number of hours actually expended much closer together. This method seems to work for me, but certainly it isn't the only system to be used. I think that experience is actually the best teacher for estimating the time required to do a project."

"Bidding a job of this magnitude requires several days," he continued. "I made a careful outline of the overall program with all the major design areas noted. Then I broke each major design area down into smaller packages to determine how complex each system or sub-part would be. At this point, the engineer has to look for any nasty, unusual design problems that might appear later, after the customer says go ahead - build it! If they appear then, it's too late to change the price."

Doug said, "You're not expected to solve all the design problems you see at this time. The idea is to recognize problem areas, determine a course of action and estimate how long it will take your group to solve the particular problem."

Exhibit A-4 shows the worksheet Doug used in estimating the time required for design of the tip tank.

Doug examined all of the design areas shown in Exhibit A-4 and estimated the required time for each. The total man-hours were then given to a Cost Accounting group. This group collects similar information from all the groups involved in the total design project and a cost figure for the customer is determined.

After two months of not hearing anything on the proposed tip tank project, the Engineering Department was notified that the customer had selected Beech Aircraft to build the aircraft. Doug said, "At this time Gene and I were told we were two months behind on the schedule! This let us know there wasn't any slack time in the project. This job had to be completed in one year from start to date of delivery of the aircraft. There was a substantial financial penalty for late delivery of the aircraft."

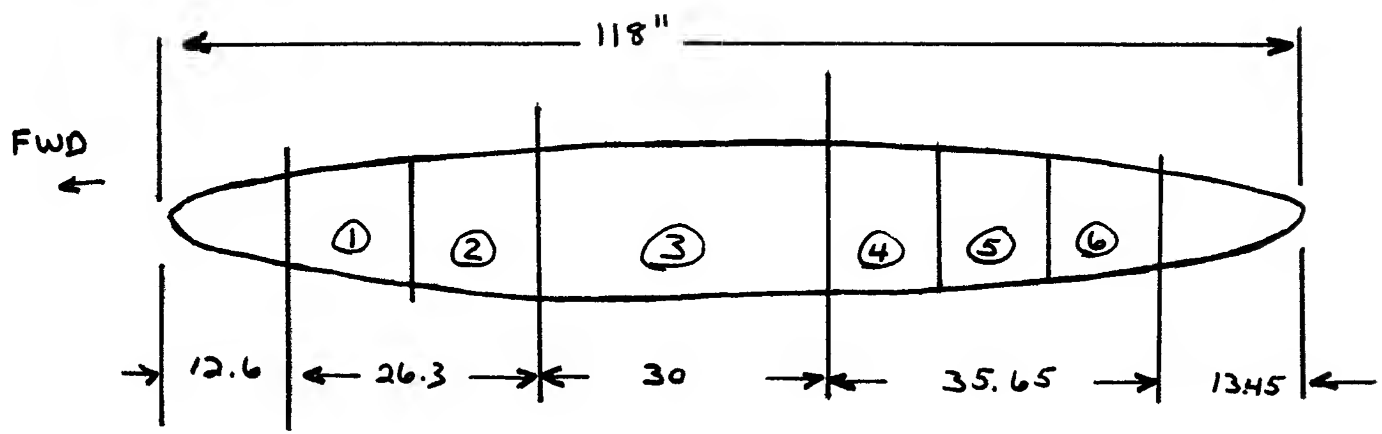
Doug said, "Looking at a project of this size, you tend to get the impression that 5 months will wrap it up. But experience shows that you can only see 30% of the work ahead, and 70% of your time will be spent on unforeseen problems and numerous minor details. This is why engineering jobs are so difficult to bid accurately."

The first order of business was to get all long lead time items like the tip tank and fuel gauging system designed or purchased as soon as they could be completely defined. Doug's supervisor, Cal Hock, proceeded to pin down the exact dimensions of the tip tank so construction by the subcontractor could begin. He made a sketch of the tank (Exhibit A-5), dividing it into 6 sections. The nose and tail sections would not contain fuel. The nose cone contains strobe lights and navigation lights while the tail cone was left dry. The volume of each of the other 6 sections was treated as a truncated cone with straight sides. Since the sides actually curved outward, a slight error on the oversize side would occur in the calculations. The calculations are shown in Exhibit A-5. A volume test of the tank run much later in the program showed that Cal was only .08 gallons off on his calculations. Cal's only comment concerning his close estimation was, "Calculators sure are more accurate these days!"

Model 200 52-Gallon Tip Tank Job Bid

Task	Hours
1. Design a separate wing tip tank fuel system installation drawing (2 J-size sheets). Drawing shall show all fuel and vent lines up to but not including equipment installation on end of integral fuel tank. Drawing shall show installation of flapper valves, drain valves, anti-siphon valve and electrical connector for fuel quantity probes.	
a. Design an access plate for fuel vents and electrical plug to pass through wall of tank. (One D-size drawing)	
2. Add a tabulation to 101-920000 to allow incorporation of tank assembly into main fuel system. (One E-size layout and two C.O.'s - change order)	
a. Design adapter plate for outboard end of integral tank.	
b. Create new fuel gauging drawing to add new fuel quantity probes to tip tank. One C.O. and D-size layout.	
3. Calibrate tip tank fuel quantity indicating system.	
4. Engineering coordination with:	
a. Globe Engineering	
b. Project Group	
c. Electrical Engineering Group	
d. Rochester Gauges, Inc.	
e. Experimental Shop (Fabrication and installation of plumbing and hardware)	
f. Flight Test Group	
g. Publications (Flight Manual and Maintenance Manual)	
h. General Electric for lightning test.	
5. Supervision.	
6. Design of the tip tank structure. This includes fuel plumbing, navigation lights installation, mounting brackets and lightning protection for the tank. Project Group will design tank fairings. 5 E-size drawings.	
7. Interpretation and analysis of ground and flight test data.	
8. Preparation of FAA certification letters and documents.	
Total	

Exhibit A-4



$$V_1 = \frac{\pi\, 12}{3}\left(7^2 + 5.55 \times 7 + 5.55^2\right) = 1491$$

$$V_2 = \frac{\pi\, 14.3}{3}\left(7.49^2 + 7 \times 7.49 + 7^2\right) = 2359$$

$$V_3 = \pi\, 7.49^2\,(30) = 5287$$

$$V_4 = \frac{\pi}{3}\, 15.2\left(7.49 + 6.83 \times 7.49 + 6.83^2\right) = 2449$$

$$V_5 = \frac{\pi\, 10.15}{3}\left(6.83^2 + 5.36 \times 683 + 5.36^2\right) = 1190$$

$$V_6 = \frac{\pi\, 10}{3}\left(5.36^2 + 3.45 \times 5.36 + 3.45^2\right) = 619$$

TOTAL VOL = 13395 IN^3 = 57.98 GAL

REQD FUEL VOL = 52.5 GAL

REQD EXP. SPACE = 244.5 x .02 = 4.89 GAL

REQD TOTAL VOL = 52.5 + 4.89 = $\boxed{57.39 \text{ GAL}}$ OK

EXHIBIT A-5

C.F. Hock
2-14-76

After the tank volume had been determined, Doug and Gene began the detail design of the individual tank parts such as bulkheads, stiffeners and skin. The outside contour and diameter of the tank was already defined by existing tooling, therefore they concentrated on the interior structure.

Doug said, "At Beech, there is no rigid distinction between a draftsman and an engineer. Degreed engineers are expected to make drawings like non-degreed engineers if their position calls for it." Doug emphasized that engineers entering the design field should expect to work on a drafting table; in his case approximately 40% of his time is spent making drawings. "The rest of your time is spent coordinating between other departments and vendors, troubleshooting production problems on the assembly line, finding solutions to problems discovered in the field after delivery and finding new vendor sources for parts and materials. The drafting phase of the project usually goes along pretty easily. Almost everything fits together beautifully on paper. It's when you start putting actual hardware together that such things as tolerances on dimensions can cause problems. That's the time the engineer should head for the shop for a good first hand look at the problem. One quickly finds that a good friendly working relationship must exist between the engineer and the manufacturing shop in order to successfully correct problems and keep on schedule. As an engineer it is not my job to assign the responsibility for an error, but to coordinate with Manufacturing to accomplish a good joint solution to any problem." Doug and Gene were both fortunate to have such a relationship with the shop and the tip tank proceeded well.

At the same time the tank structure was being designed, Doug was in communication with the fuel gauging system manufacturer. Doug recalled that three fuel quantity gauging systems were presented to the customer; no gauging system in tip tank, a gauging system independent of the main fuel quantity gauging system, and an integrated main and tip tank gauging system. The customer had selected the independent tip tank gauging system because of its simplicity and low cost.

Scale drawings of the tip tank were sent to the fuel gauging system manufacturer (vendor) showing various cross section cuts through the tank. From this information the vendor determined the fuel quantity transmitter float arm postitions corresponding to full, 3/4 full, 1/2 full, 1/4 full and empty. The fuel quantity transmitter is essentially a reostat which has a full scale output of 90 olms. Therefore, taking into account the contour of this unusually shaped tank, the vendor had to position the float arm to produce the proper resistance corresponding to a given fuel quantity. "Needless to say, this is a difficult task and can lead to a lot of trial and error," Doug said.

At the same time design of the tank and coordination with the fuel quantity gauging manufacturing was going on, other details were being examined also. "Soon it was like a multi-ring circus with many detail parts being discussed, analyzed and decisions being made simultaneously," Doug recalled. This was all necessary in order to get the tanks built, tested and certified on time. However, this is not at all unusual! Almost all projects run at a quick pace requiring attention to many details on several items at the same time."

TIP TANKS FOR THE BEECH SUPER KING AIR

Part B

Testing the Tip Tanks

By mid-June 1976, the first prototype tip tank was completed by the subcontractor, Globe Engineering, and shipped to Beech for testing. The first test scheduled was to confirm the tank's actual volume. If the volume of the tank was less than the required 52 gallons, there would be no need to test any further. A new larger tank would have to be designed. Doug said, "This was the first of several tests which made me a little tense. When one realizes that several thousand dollars have been spent along with 6 months time to build this tank, now is not a time to discover you made a small error in calculating the tank's volume. At this point in the program no error is small!"

The tank was positioned on a table with its nose 3° down, just as it would be on the aircraft when parked on the ground. The tip tank had to be positioned this way so that in flight it would be level and all the fuel could drain by gravity into the main fuel system. Vent lines entering the tank were sealed and the tank filled with water. To Doug's frustration the tank's total volume was only 54 gallons. He knew that to meet the design goal of 52 gallons of fuel plus 5 gallons for fuel expansion space, he must have 57 gallons in the tank. He remembered there was still a little volume that would be gained when the gravity feed lines and the volume in the original wing tank around the old fuel filler cap, filled with fuel. However, Doug had estimated that volume to be approximately 2 to 3 gallons and this was his safety margin for error so it couldn't be counted on for use at this time.

Doug said, "We drained the tank and examined the internal plumbing through an access hole. We found that an air vent tube was bent so that an excess amount of air was trapped in the top of the tank preventing additional water from being added." The tube was removed and the bend angles adjusted several times to get a good fit in the tank. "We noted the angles for future reference. We also discovered that a vent check valve, designed to allow air to escape from the tank but retain the fuel was slightly sticky. We activated it several times to loosen its seals and ran the test again. This time the tank held exactly 57.9 gallons. That was very close to the calculated volume of 57.98 gallons."

"The next portion of this test was to measure the resistance output of the fuel quantity transmitter vs. fuel level and fuel quantity in the tank," Doug continued. "This data was obtained by filling the tank in 5-gallon increments while we measured the output resistance of the transmitter and the depth of fuel in the tank. We used PD680 solvent which has similar characteristics to fuel but is not so flammable." This data was compared to that supplied by the transmitter manufacturer and found to be inconsistent at both the empty and full positions. The float arm was readjusted by bending and the new angle in the arm noted so the vendor's drawings could reflect the change. This time the test produced more accurate results and Doug notified the vendor of the change made to his prototype transmitter.

The same day the volume test was completed, the tip tank was sent to the Structural Dynamics Engineering Test Group for a "slosh and vibration" test. This is a 25-hour vibration test required by the Federal Aviation Administration[1] (FAA) and specified by Federal Air Regulation section 23.965(a2) (Exhibit B-1). "The purpose of this test is to prove structural integrity of the tank design," Doug said. "The basic test requirements, as stated by the FAA, are that the tank assembly must be vibrated for 25 hours at an amplitude of not less than 1/32 inches while 2/3 filled with water or other suitable test fluid. During the test, the tank assembly must be rocked at a rate of 16 to 40 complete cycles per minute, through an angle of 15 degrees on either side of the horizontal (30 degrees total). The FAA also requires that the vibration frequency be determined from critical engine speed vibration tests. These tests had been conducted in 1973 when the model 200 was first built and the frequency found to be between 16 and 40 Hz." The Structural Dynamics Engineering Group issued the test request shown in Exhibit B-2 to the shop to perform the slosh and vibration test.

The vibration table is a large steel table approximately 6 feet by 10 feet long (See Exhibit B-3) which vibrates through connecting rods attached to eccentric weights. At the same time the table is vibrating it is also pitching up and down through a 30-degree arc.

The tank was rigidly mounted to the vibration table to simulate installation on the aircraft. The wing tip tank support bracket was attached to a heavy steel bracket bolted to the table frame as shown in Exhibit B-3. The tank was then filled 2/3 full of water containing a red dye. Doug said, "The dye makes any cracking easy to see. We thought the rigid mounting would be conservative because the actual wing attach point on the aircraft is more flexible. This means the attach point vibration amplitude would be less in the actual installation than on the vibration table." The tank used baffles with several holes in them to check the flow of fluid flowing forward and aft during the pitching motion. These baffles also doubled as the main bulkheads in the tank for structural strength.

The tank was instrumented with four accelerometers on the main spar fitting to measure vertical and horizontal loads. Doug said, "The spar fitting was judged to be the area of highest stress and lowest amplitude level. The vibration table was then adjusted to produce ±.031 inches amplitude at this fitting, which was also the logical place for the accelerometers." The test began with the tank oscillating ±15 degrees up and down 20 times a minute. High speed motion pictures were taken and a strobe light was used for continuous observation.

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[1] Federal Air Regulations, U.S. Government, Department of Transportation, 1976 Edition, Page 125.

(2) except as noted below, the tank assembly must be vibrated for 25 hours at an amplitude of not less than $\frac{1}{32}$ of an inch (unless another amplitude is substantiated) while $\frac{2}{3}$ filled with water or other suitable test fluid.

(3) The test frequency of vibration must be as follows:

(i) If no frequency of vibration resulting from any r.p.m. within the normal operating range of engine speeds is critical, the test frequency of vibration, in number of cycles per minute, must be the number obtained by multiplying the maximum continuous engine speed (r.p.m.) by 0.9.

(ii) If only one frequency of vibration resulting from any r.p.m. within the normal operating range of engine speeds is critical, that frequency of vibration must be the test frequency.

(iii) If more than one frequency of vibration resulting from any r.p.m. within the normal operating range of engine speeds is critical, the most critical of these frequencies must be the test frequency.

(4) Under subparagraph (3) (ii) and (iii) of this paragraph, the time of test must be adjusted to accomplish the same number of vibration cycles that would be accomplished in 25 hours at the frequency specified in subparagraph (3) (i) of this paragraph.

(5) During the test, the tank assembly must be rocked at a rate of 16 to 20 complete cycles per minute, through an angle of 15 degrees on either side of the horizontal (30 degrees total), about an axis parallel to the axis of the fuselage, for 25 hours.

(c) Each integral tank using methods of construction and sealing not previously proven to be adequate by test data or service experience must be able to withstand the vibration test specified in subparagraphs (1) through (4) of paragraph (b).

(d) Each tank with a nonmetallic liner must be subjected to the sloshing test outlined in subparagraph (5) of paragraph (b) of this section, with the fuel at room temperature. In addition, a specimen liner of the same basic construction as that to be used in the airplane must, when installed in a suitable test tank, withstand the sloshing test with fuel at a temperature of 110° F.

§ 23.967 Fuel tank installation.

(a) Each fuel tank must be supported so that tank loads are not concentrated. In addition—

(1) There must be pads, if necessary, to prevent chafing between each tank and its supports;

(2) Padding must be nonabsorbent or treated to prevent the absorption of fuel;

(3) If a flexible tank liner is used, it must be supported so that it is not required to withstand fluid loads;

(4) Interior surfaces adjacent to the liner must be smooth and free from projections that could cause wear, unless—

(i) Provisions are made for protection of the liner at those points; or

(ii) The construction of the liner itself provides such protection; and

(5) A positive pressure must be maintained within the vapor space of each bladder cell under any condition of operation, including the critical conditions of low air-speed and rate of descent likely to be encountered.

(b) Each tank compartment must be ventilated and drained to prevent the accumulation of flammable fluids or vapors. Each compartment adjacent to a tank that is an integral part of the airplane structure must also be ventilated and drained.

(c) No fuel tank may be on the engine side of the firewall. There must be at least one-half inch of clearance between the fuel tank and the firewall. No part of the engine nacelle skin that lies immediately behind a major air opening from the engine compartment may act as the wall of an integral tank.

(d) No fuel tank may be in the personnel compartment of a multiengine airplane. If a fuel tank is in the personnel compartment of a single engine airplane, it must—

(1) If no larger than 25 gallons total capacity, be properly drained and ventilated; and

(2) If larger than 25 gallons total capacity—

(i) (For a conventional fuel tank) be isolated from the personnel compartment by fume and fuel proof enclosures; or

(ii) (For a bladder type fuel cell) have a retaining shell that is at least equivalent to a metal fuel tank in structural integrity and in fume and fuel

Exhibit B-1. Excerpts From Federal Aviation Regulations

ECL 246B

Beech Aircraft Corporation

REVISION (A)

ENGINEERING TEST REQUEST

NO. 101E781

REVISED 5-10-76 (A)

DATE ~~3-29-76~~

FROM E. H. Hooper

TO P. A. Jackson

CC: W. G. Pierpont, H. P. Flory, L. B. Clay, GE Files

MODEL 200

WORK ORDER 12649

ENGINEERING DATA:

SLOSH AND VIBRATION TEST OF WING TIP TANK - 101-920070

PURPOSE - The purpose of this test is to subject the tip tank to slosh and vibration test to simulate the actual condition and check for leakage or failure of the specimen. Certification to FAR 23.965 required.

TEST SPECIMEN - The test specimen is supplied by the Project Group (contact Leroy Clay). The test specimen must be structurally complete, but system items may be omitted at discretion of Dynamics Engineer.

TEST SETUP AND PROCEDURE -

(a) Attach the test specimen to the slosh platform utilizing major structural elements, to simulate the support of the tank as installed in an aircraft. The test tank should be mounted such that its chordwise axis approximately parallels the long axis of the slosh platform and oscillations occur about an axis that would be perpendicular to the aircraft centerline.

(b) The tank shall then be filled with water to 2/3 capacity.

(c) During the test, the tank assembly must be rocked about a pitching axis at a frequency which should be determined after some trials. The frequency may be 16 to 40 cycles per minute, through an angle of 15° on either side of the horizontal (30° total). Simultaneously, the tank must be vibrated in the vertical direction at approximately 1800 cycles per minute at an amplitude of at least 1/32 of an inch. (A)
The duration of the test should be 25 hours.

INSPECTIONS - Inspection for leakage and structural failure should be conducted at 5 hour intervals. If leakage is noted at less than 5 hour intervals, the test should be stopped.

Photographs of the test setup and structural failure, if any, are required.

APPROVED - A REVISION

E. H. Hooper

EXHIBIT B-2

90-33089

APPROVED E. H. Hooper

APPROVED L. B. Clay

EXHIBIT B-3

After a little more than 2 hours of this test, the tank cracked in the weld area where the spar fitting went through the skin of the tank into the tank bulkhead. Also, the aft bulkhead attached to the rear stabilizer cracked at a hole in the bulkhead (Exhibits B-4 &-4A). Doug said, "We felt we either had stresses higher than anticipated from the structural and dynamic load analyses or else the stresses produced in the test were at places we did not expect them to be."

A meeting was called between the Propulsion Systems Group, the Structural Test Group and the Project Engineering Group to discuss the possible causes of the tip tank's failure. Doug recalled, "We all agreed that the imposed stresses from bending were designed to flow from the bulkhead ring into the main spar fitting and into the wing. The tank had been designed with a weld around this fitting at the tank skin to seal it fuel tight. We decided that this weld was short circuiting the stress flow and causing the stresses to concentrate at the intersection of the spar fitting and skin. We also thought the single aft bulkhead was receiving an excessive amount of vibration due to the rigid mounting to the vibration table. We reviewed the calculations for the stresses and rechecked the standard safety margins which had been designed into the tank. We decided to provide an even larger safety margin structurally in this area to eliminate any reoccurrence of cracking."

A new tip tank was then built with the weld around the main spar fitting removed and replaced with a flexible sealant. Also, the single .040 thick bulkhead was replaced with two .061 bulkheads placed back-to-back on either side of the spar fitting.

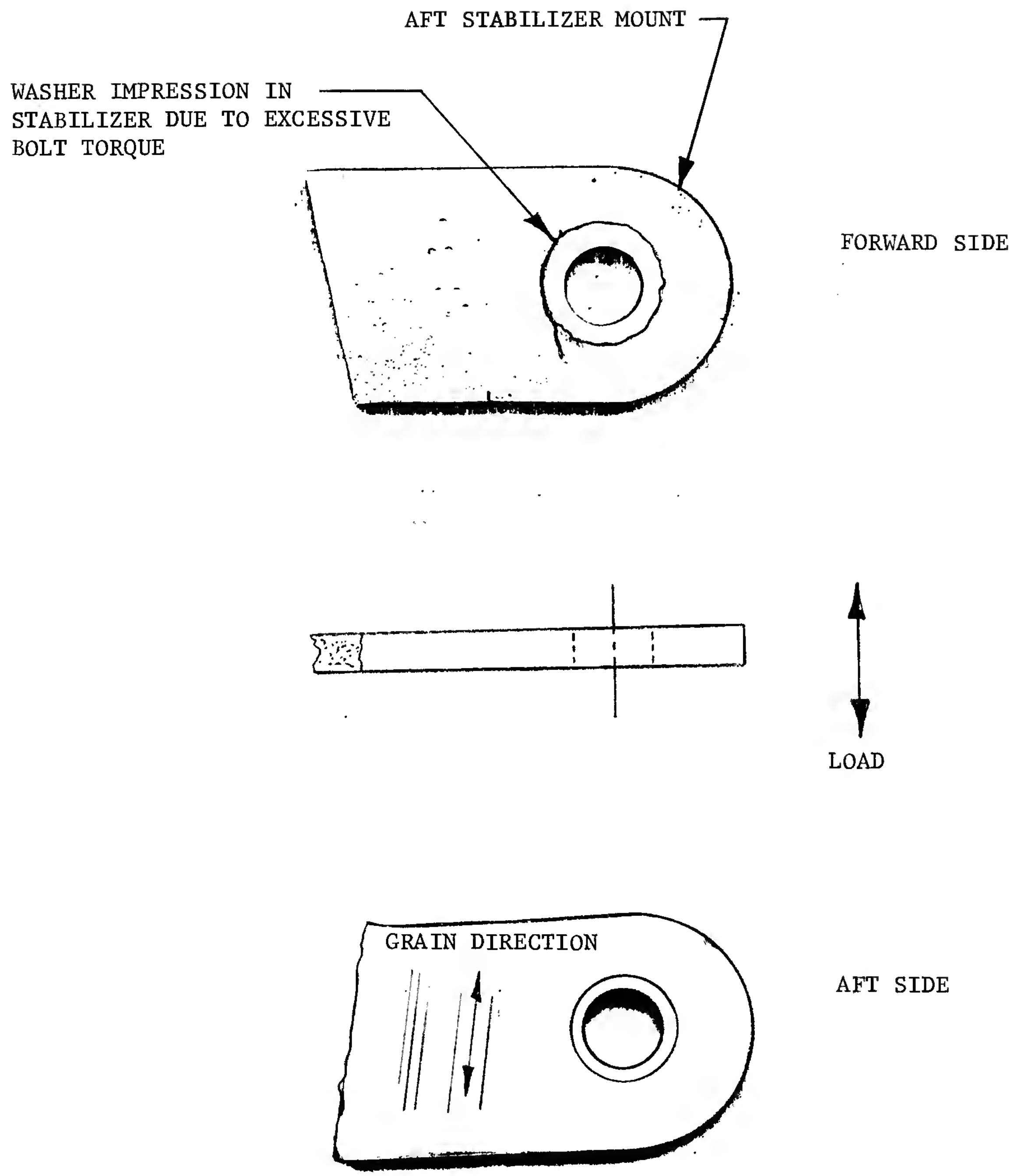
Five weeks later the new tip tank (Design #2) was mounted on the vibration table just as before and the test began with zero time on the tank. The Beech engineers were optimistic that this test would prove out their theory of stress concentration in the weld as the cause of the first failure. But this time, a problem developed in a different area. The aft stabilizer mount fractured at a point 3 inches from the attach point (See Exhibit B-5) to the vibration table. Doug said, "It now seemed apparent that the stress levels present were much higher than had been expected. We thought the test procedure should be examined for accuracy and more realistic simulation of the actual installation."

The aft stabilizer mount was repaired with a splice plate and the water was replaced with jet fuel having less weight. The fuel volume was decreased from 39 gallons to 35 gallons due to an error in interpreting the tank's total volume. The test personnel originally thought the liquid capacity of the tank was 58 gallons; however, the liquid capacity was never more than 53 gallons. Doug said, "The total volume of the tank; liquid and expansion air space was indeed 58 gallons. This change produced an 86 pound reduction in the total tank weight."

BEECH AIRCRAFT CORP.

EXHIBIT B-4

EXHIBIT B-4A



TORQUE WAS TOO HIGH ON ATTACH BOLT AND
GRAIN DIRECTION WAS WRONG WAY

EXHIBIT B-5

"The FAA was contacted by telephone and asked to come out and inspect our test equipment and procedures," Doug continued. Specifically, Beech wanted to know if the test was too severe. An FAA test engineer examined the test setup and advised Beech that we had erred in interpreting the FAA test requirements. The requirement of a vibration amplitude of .031 inch was not at the point of minimum amplitude, but was an average amplitude along the length of the tank. We were all a little upset that the regulation had not spelled this out."

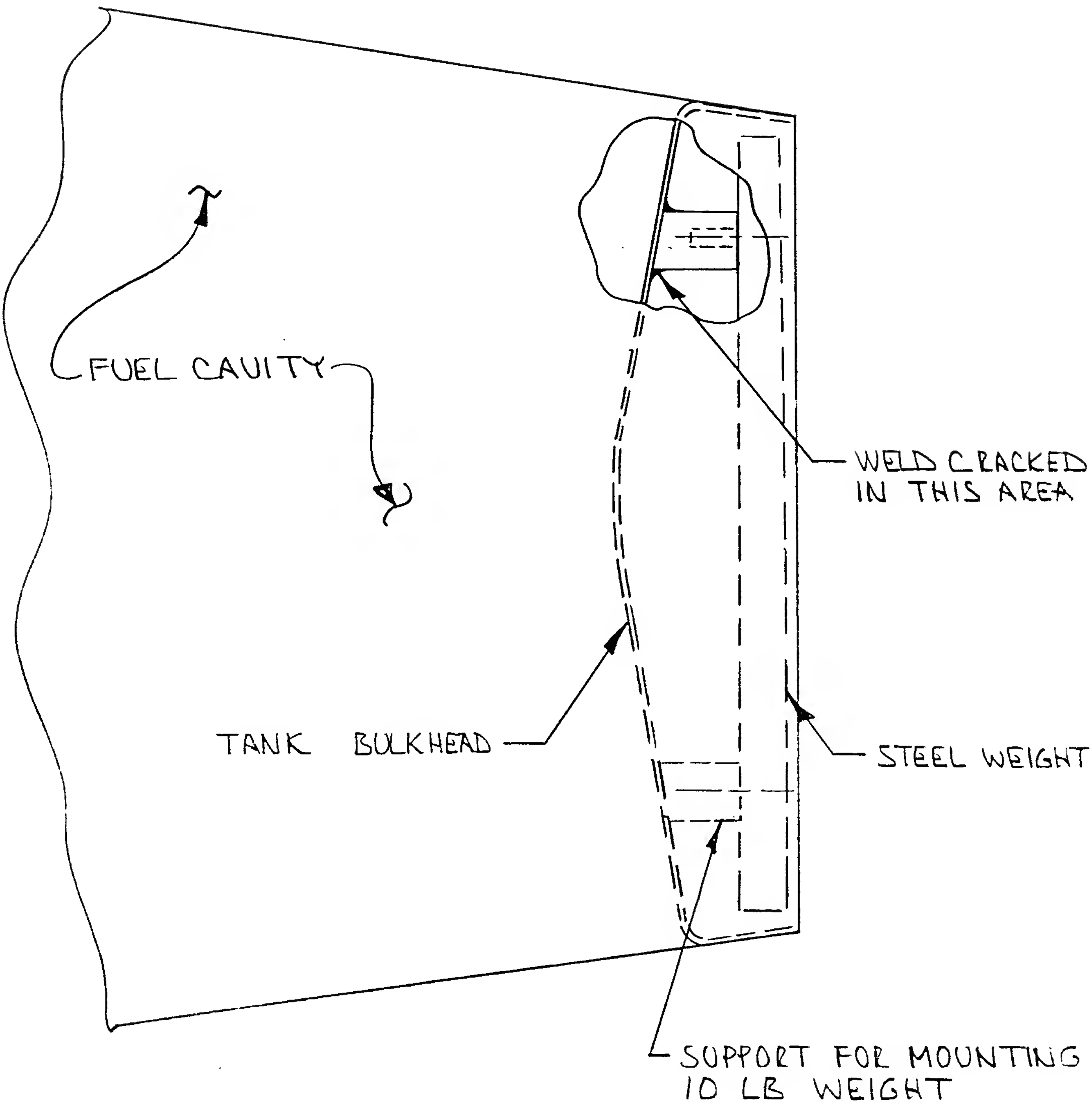
Therefore, amplitude readings were taken using accelerometers at eleven locations along the length of the tank and averaged together. The vibration level was adjusted until the average was ±.031 inches or greater and test #3 was started.

Test #3 was also short lived, lasting only 7 hours before the nose weight support boss cracked the forward bulkhead at a weld joint (Exhibit B-6). The function of the nose weight was to provide stability against pitching in flight when the tank was empty. (Later in the program the weight was found not to be necessary and was removed.) This bracket was screwed to the walls of the tank rather than welded (see Exhibit B-7). This provided a little more flexing in the mounting bracketry and was the easiest means of reworking the existing tank. This configuration began test #4.

Test #4 ran for 1.5 hours until a crack in the skin was found at the main spar bracket on the lower side (see Exhibit B-8). "The crack was under the sealant which was added during test #2," Doug said, "and had probably been growing undetected. We quickly designed a heavy skin doubler from .080 thick 2024-T4 aluminum sheet and installed it around the main spar fitting using .12 inch diameter rivets. Sealant was used between the doubler and the tank skin to prevent leaks around the rivets. This became test #5 and proved to be the final design configuration. The test was continued for 25 hours and 16 minutes, giving a total time on the tank of slightly less than 34 hours. The tank was declared a success, as it had exceeded the minimum FAA test requirements (25 hours) by almost 9 hours.

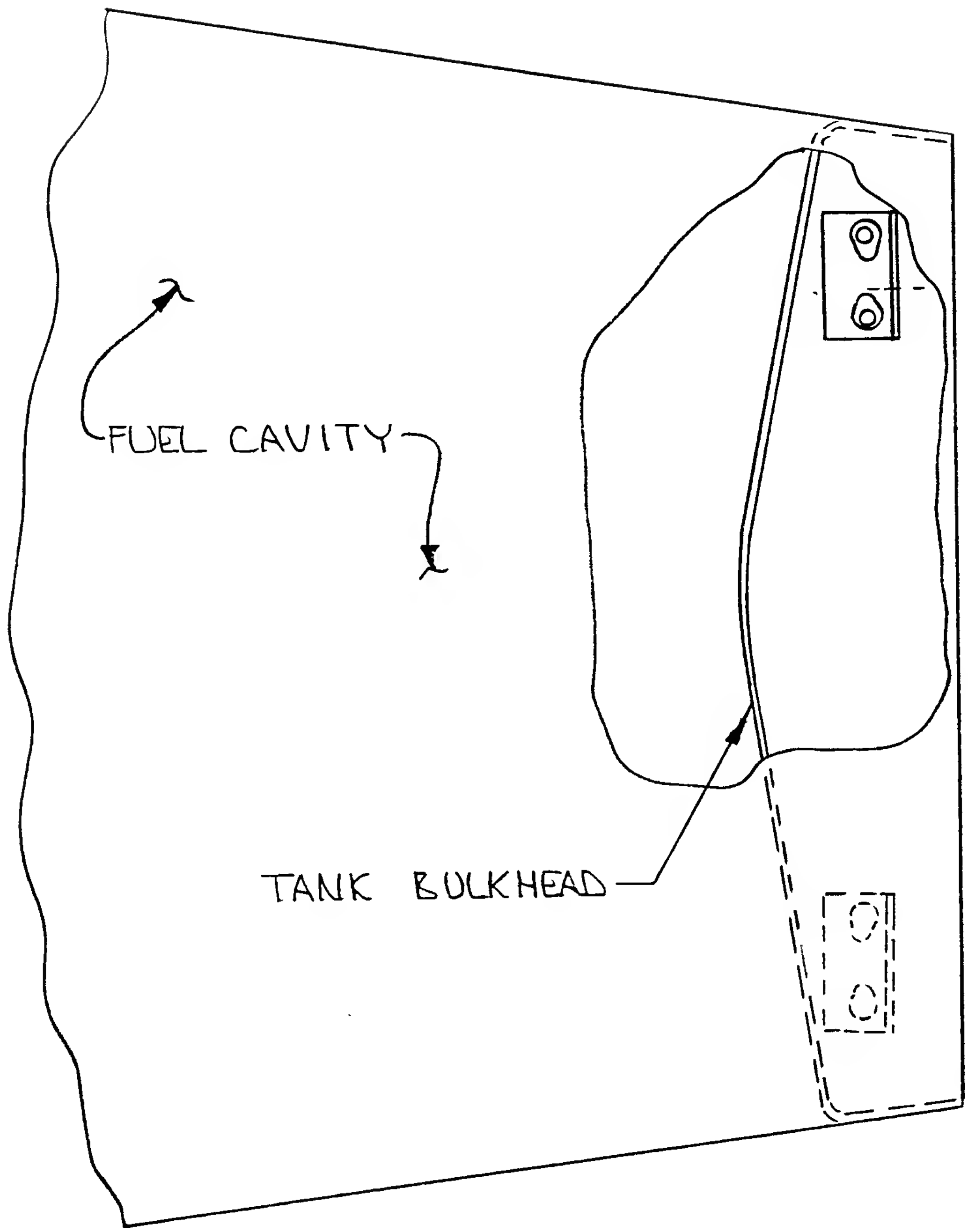
The final structural test for the tip tank was an ultimate pressure test. "This test is designed to determine the tip tank's structural integrity under internal pressure," Doug related. The tip tank was sealed off and pressurized with nitrogen from a high pressure bottle. The pressure was increased to 12.3 psig and held there for one minute to check for leaks. The pressure was then increased to 15.0 psig and held for two minutes.

Doug said, "The tank was 15 inches in diameter with an .080 inch wall, so this gave a stress of about 1400 psi. The tank skin was 6061-T42 aluminum, which has a yield strength of 19,000 psi. This provided a big safety factor but the .080 inch skin thickness was dictated by lightning protection requirements, not structural requirements." No leaks were detected and the test was terminated. A thorough examination was made of the tank to determine if any permanent deformation of the tank walls had occurred, however none was found.



FWD SECTION OF TIP TANK

EXHIBIT B-6



FWD SECTION OF TIP TANK

EXHIBIT B-7

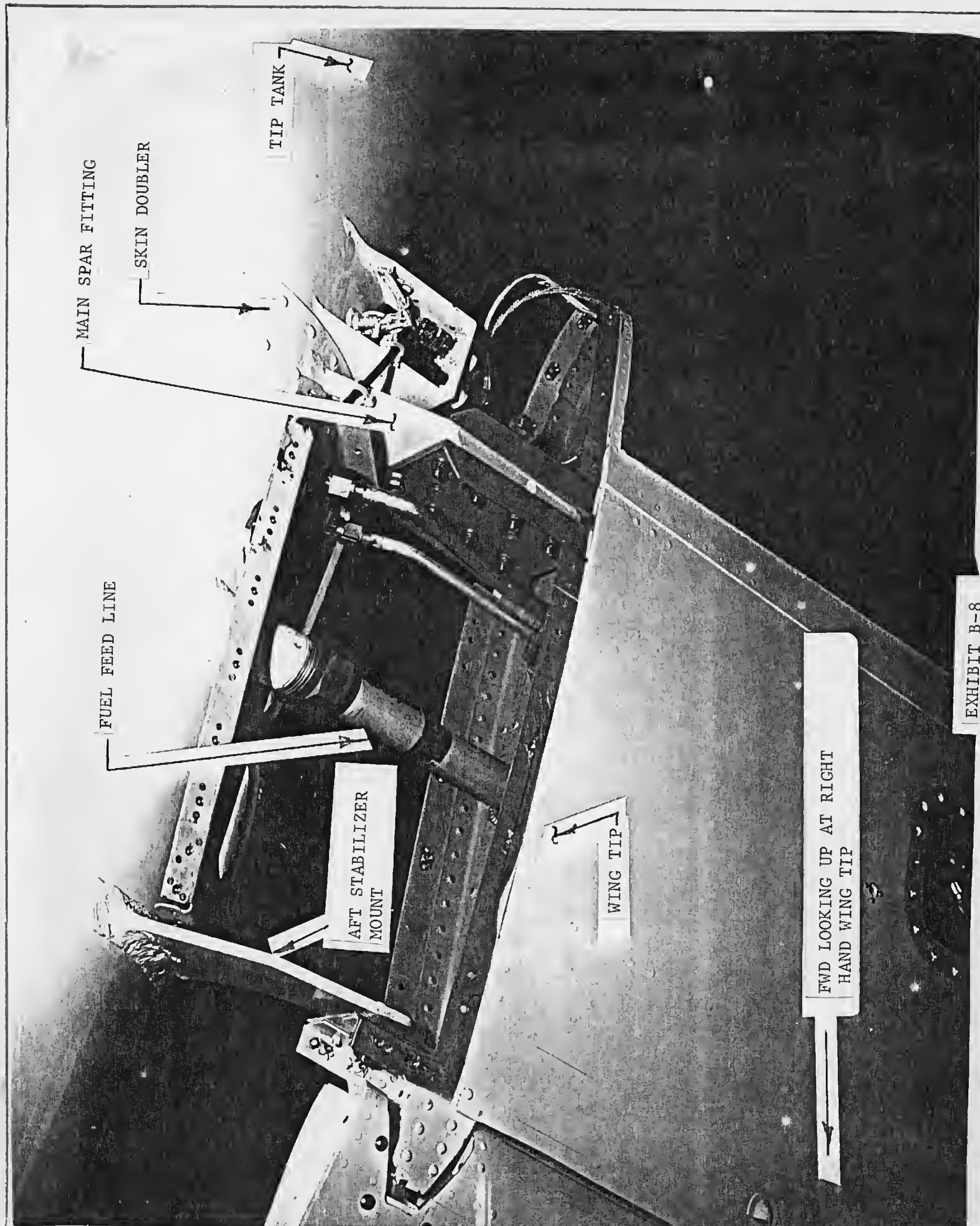

MAIN SPAR FITTING
SKIN DOUBLER
TIP TANK
FUEL FEED LINE
AFT STABILIZER MOUNT
WING TIP
FWD LOOKING UP AT RIGHT HAND WING TIP

EXHIBIT B-8

The next test scheduled for the tip tank was the actual flight test to determine if fuel would feed from the tank and also to check the operation of the fuel vent system. The tanks and their associated plumbing and wiring were installed on a test aircraft which had a modified wing to accommodate its installation. The left tip tank and wing were filled with fuel and found to hold 325 gallons. The right hand tip tank and wing held the same amount. Doug said, "These quantities indicated the tip tank held 53 gallons (determined from the first volume test) plus 2 additional gallons per side which were picked up from filling the plumbing lines and expansion spaces in the wing itself. The total fuel system expansion space was now located in the tip tank."

The first flight test had several surprises for Doug; one of them totally unexpected. "Soon after takeoff, the pilot noticed the left lightning diverter located on the extreme trailing end of the tip tank was missing (Exhibit B-9). A quick look at the right hand tip tank showed no lightning diverter there either. The pilot and I agreed that the lightning diverters had been in place before takeoff. We landed, and I examined the mounting bracket for the lightning diverter. The metal base of the diverter was still attached to the tip tank but the non-metallic shaft was missing. Something must have broken both diverters off at the base soon after takeoff. Since no one observed this incident, two new diverters were installed and another flight was scheduled. This time two people were assigned to watch both diverters continuously during takeoff and flight." Soon after takeoff, both diverters began to vibrate, causing a blurred cone-shaped appearance until they fatigued at the base and broke away from the aircraft. "It wasn't too difficult to see that a vortex air flow off the tip tank had made the diverters oscillate about the axis of the tank," Doug continued. "In other words, the symmetry of the diverter installation was causing the diverter to follow the air flow in a spiral path until it broke from fatigue.

"The solution to this problem seemed to be to eliminate the symmetry of the installation. If the diverter was moved out of the center of the vortex air flow, then continuous circular motion should cease. Therefore, we angled the mounting of the diverter base attach point 25° outward (Exhibit B-9A) and this configuration was test flown. The 25° angle was arbitrary and could have been changed if required. The diverters were carefully observed throughout the next flight and no oscillatory motion was observed. The lightning diverters presented no further problems."

With this problem solved, the next test was to check out the fuel vent system. This test consisted of putting the aircraft through various flight maneuvers to make sure fuel would feed into the wing. The FAA requirements state, "A positive pressure must be maintained within the vapor space of each (fuel tank) under any condition of operation . . ."[2] The tip tank was instrumented with small plastic hoses which were connected to pressure gauges in the aircraft cabin. Doug said, "The pilot put the plane into a series of side slips and the air pressure above the fuel in the tank remained positive.

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[2] Federal Air Regulations, U.S. Government, Department of Transportation, 1976 Edition, Paragraph 23.967(a)

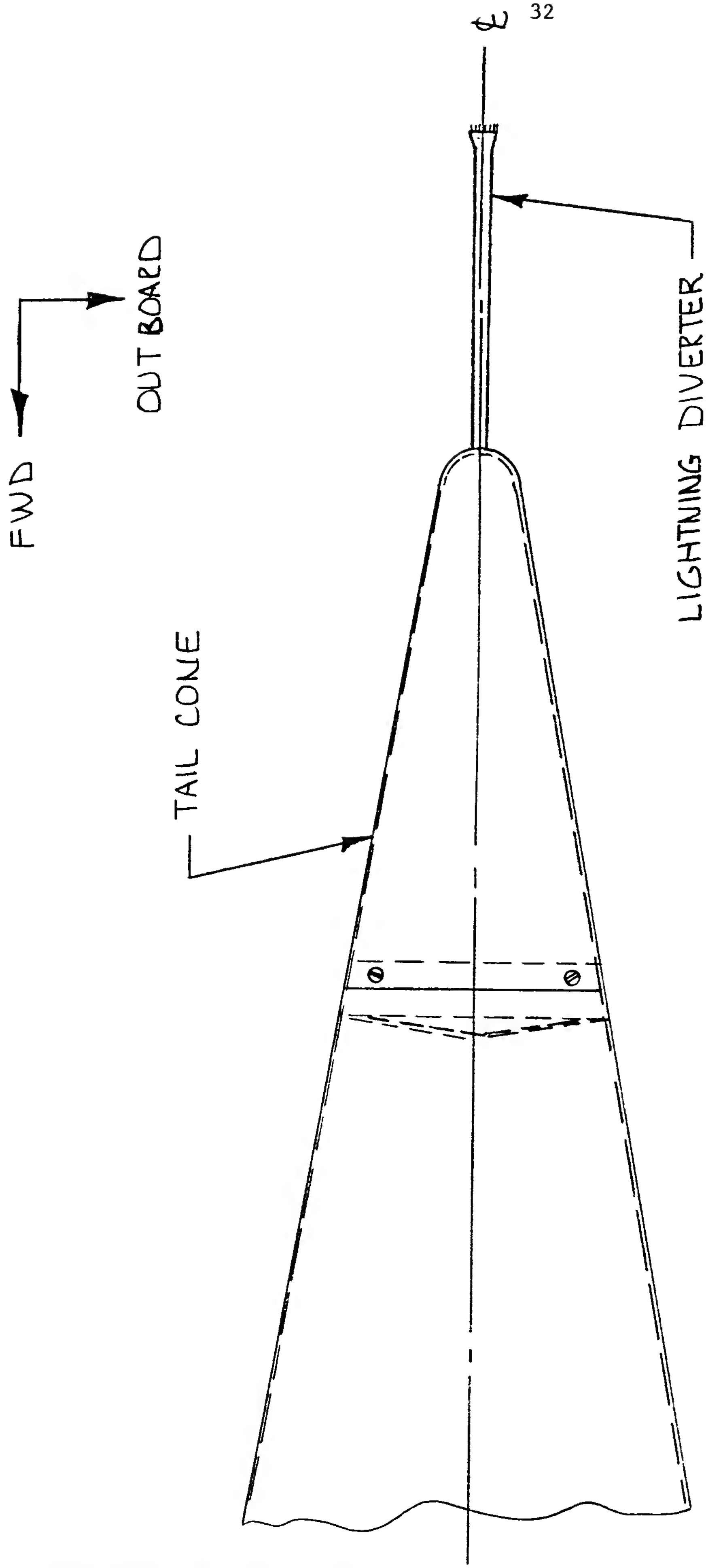


EXHIBIT B-9

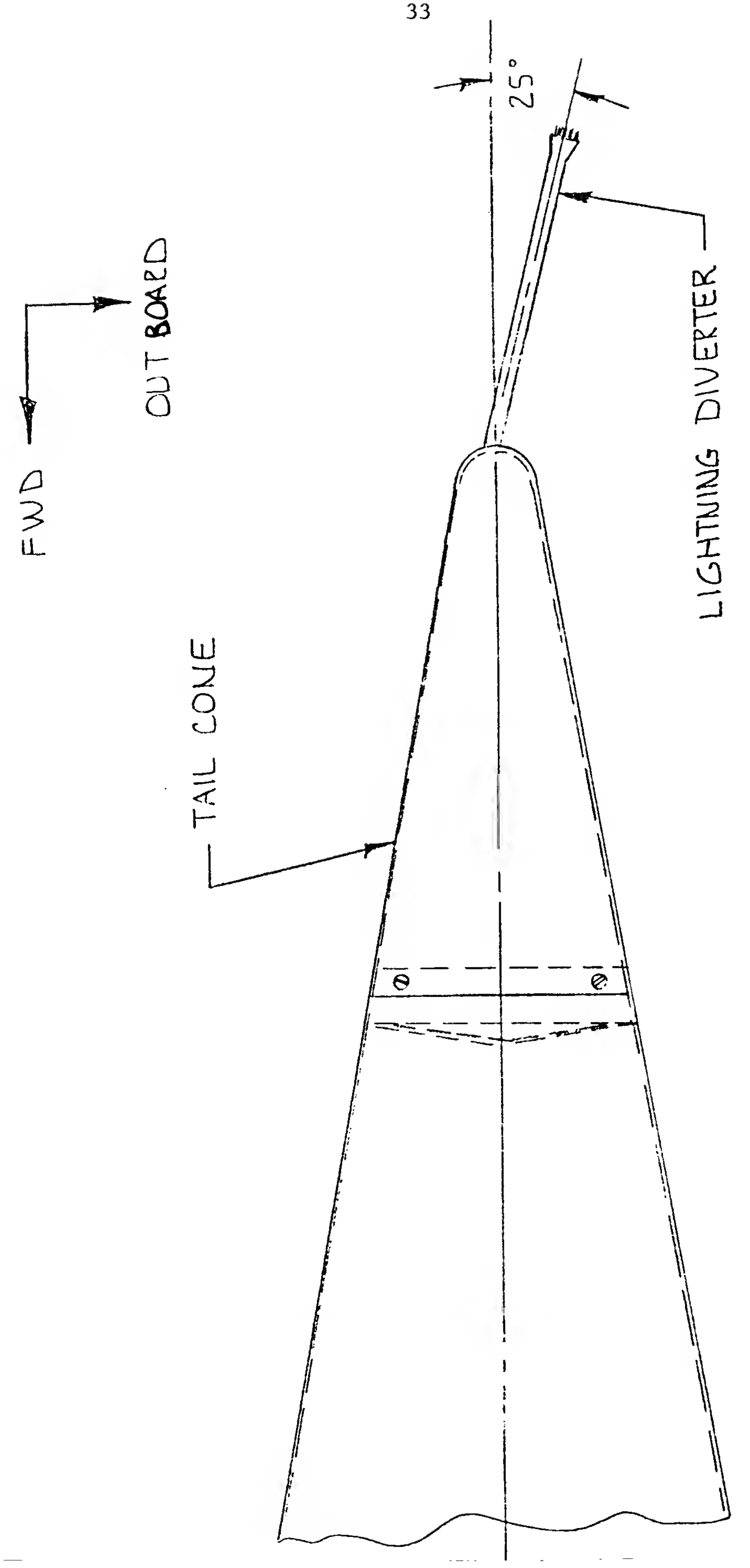
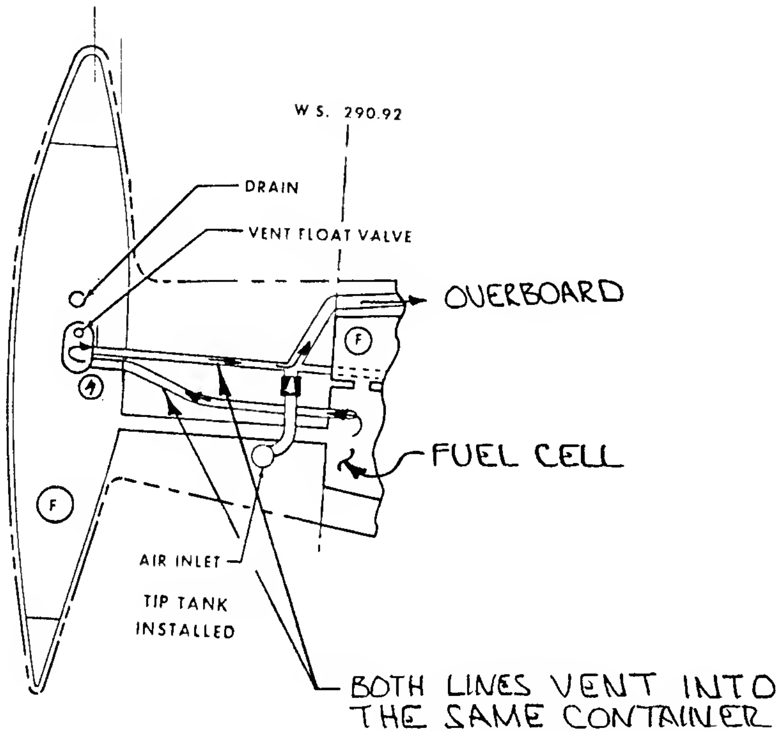


EXHIBIT B-9A

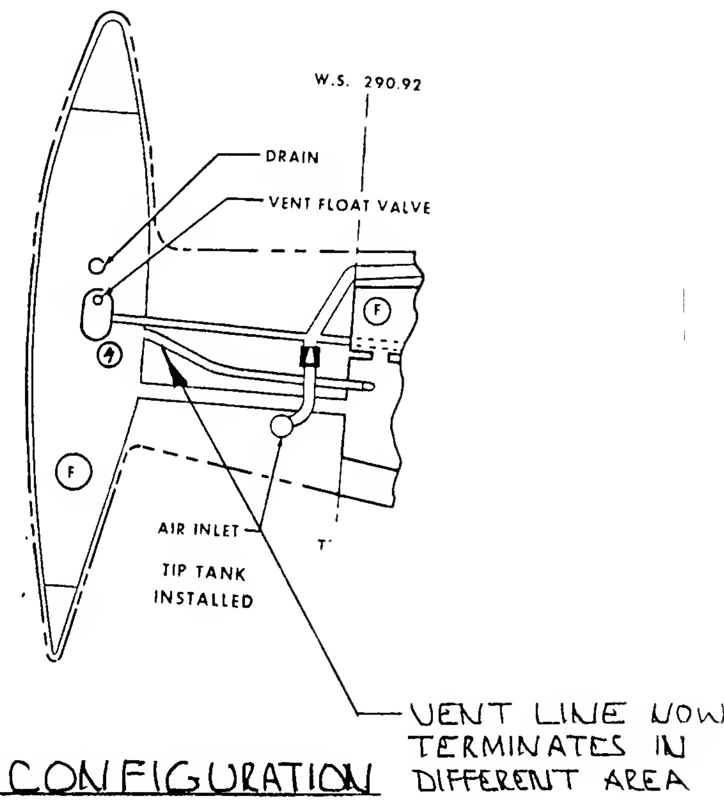
However, we could see a continuous stream of fuel pouring from the fuel vent under the wing. We landed and I disassembled the vent lines leading into the tip tank. I thought maybe a pressure relief valve was opening prematurely due to the fuel surging back and forth. However, the valve was working okay. Next we measured the fuel surge pressure using pressure transducers and found it to be below the valve's release point. At this point we decided to take another hard look at the original vent system design. Originally, when I designed the tip tank fuel system, it had seemed necessary to interconnect the vent line between the tip tank and the wing tank in order for the air pressure in the tanks to remain equal. I now went back and studied the system layout in detail, making a fuel system schematic of the tip tank area. A schematic is a diagram of how all the plumbing is interconnected, and can be useful in troubleshooting system problems (see Exhibit B-10). I found that the tip tank vent line interconnected with the overboard vent line through a common vent chamber. This allowed an open path for the fuel to flow overboard when the wings were not level. Looking at the fuel system schematic, it was obvious that the solution to the fuel dumping problem was to isolate the two vent lines. Schematics are very good in understanding how a system operates as opposed to how it's put together. The usual engineering drawing gives all the details of how to put a system together including part numbers, assembly instruction, etc. This makes it somewhat difficult to see what's really happening within the system itself." The two fuel lines were isolated through rerouting of the plumbing. The system was checked on the next flight and and no fuel dumping occurred throughout the remainder of the test program.

The final test to be performed on the tip tank was a lightning strike test. The purpose of this test was to insure that if the tip tank was hit by lightning, no damage of any consequence would occur. Doug said, "We know from experience that an aircraft's wing tips are a favorite location for lightning strikes, therefore precautions were taken to protect that area. We hired General Electric Company to perform the test because Beech does not have the facilities to do so. We shipped them the entire aircraft wing with the tip tank installed on it."

Doug said the plexiglas nose cone was shielded by three very thin aluminum strips glued to the outer surface (Exhibit B-11). These strips were designed to vaporize when hit by lightning and the strip would provide an ionized air path to the rear edge of the nose cone where it would transfer to the aluminum aircraft skin. Doug stated, "This all sounded good in theory, but now we were about to see if it really worked. In the last 10 years, much research has been done in the area of determining the voltage and current found in lightning. It has been found that nearly all lightning strikes have voltages less than 150,000 VDC and the current is less than 200,000 amps. Therefore, these two values were used as the test criteria as recommended in FAA documentation reports and by the Society of Automotive Engineers."



FIRST DESIGN



FINAL CONFIGURATION

EXHIBIT B-1D

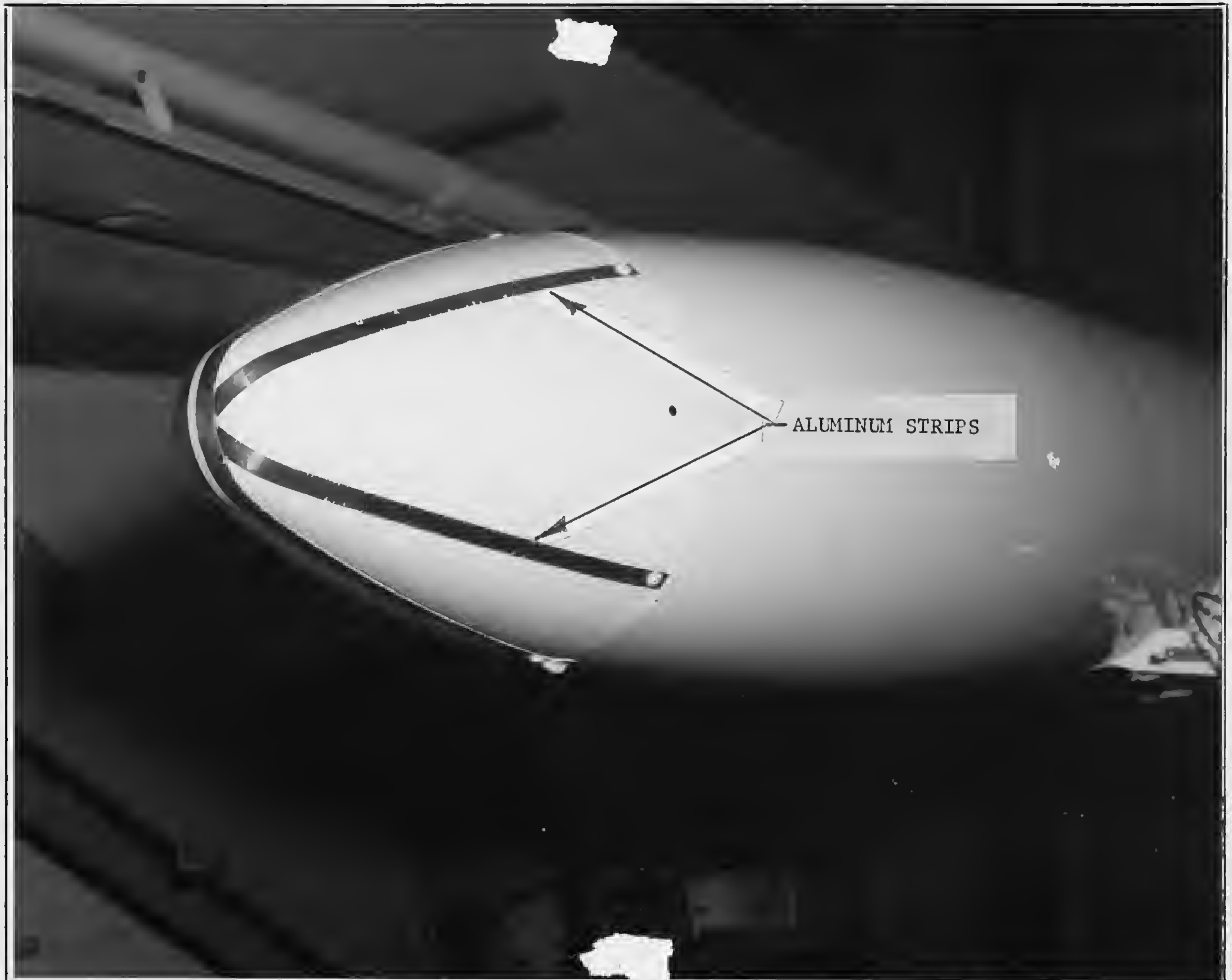


Exhibit B-11

"The lightning test set-up was very impressive," Doug said. "Our test wing with the tip tank installed was mounted horizontally in a large test cell at General Electric. The wing was electrically joined to the ground or negative side of a very large DC current surge generator (Exhibit B-12). A long movable arm with the positive probe attached was positioned within 12 inches of the portion of the tank being tested. This probe was connected to a large bank of capacitors where the charge was built up and then discharged at the proper time.

"The nose cone was the first to be tested," Doug said, "and it passed the test beautifully. The strips of aluminum vaporized and discharged into the aircraft skin." Then the test engineer at General Electric asked, "What happens if the aluminum foil is removed?" There was one way to find out and this test had surprising results. The plexiglas took the lightning strike without any damage. Doug said, "Plexiglas is one of the strongest plastics in use and was able to transfer the electrical charge along its outer surface into the aluminum skin. To show that the one test was not an accident, the test was repeated four more times until the nose cone finally split. We weren't too concerned after the fourth strike since five lightning strikes to the same nose cone are highly improbable."

Similar tests were performed on the lightning diverter mounted on the trailing end of the tank. Again there was no damage to the tank; however the lightning diverters were damaged on the third strike. Doug said, "Whenever an aircraft crew suspects they were hit by lightning, it is a general practice to make a thorough examination of the exterior of the aircraft after landing to look for damage. The diverters are easily removed and replaced and are relatively inexpensive. The probability of an aircraft getting hit by lightning three times in the same place on the same flight is extremely remote."

The last lightning test was performed by striking an access cover on top of the tank. Doug said, "It had already been proven by previous tests several years ago that aluminum .080 inches thick would not be penetrated by lightning. However, in this case we had a cover plate with a non-conductive rubber gasket under it. This proved to be a poor conductive path for the lightning to take." General Electric engineers mounted a camera inside the tank with the lens open. "When the lightning hit the cover plate," Doug recalled, "the camera recorded a small flash of light. This told us that we had poor conduction between the cover plate and a metal bracket inside which supported a fuel vent tube. The current was jumping from the cover through the rubber gasket to the metal bracket." General Electric suggested Beech make the bracket from a non-conductive material such as plastic so the current would not arc across to it. Therefore a new bracket was made in exactly the same shape but the material was changed from aluminum to plastic.

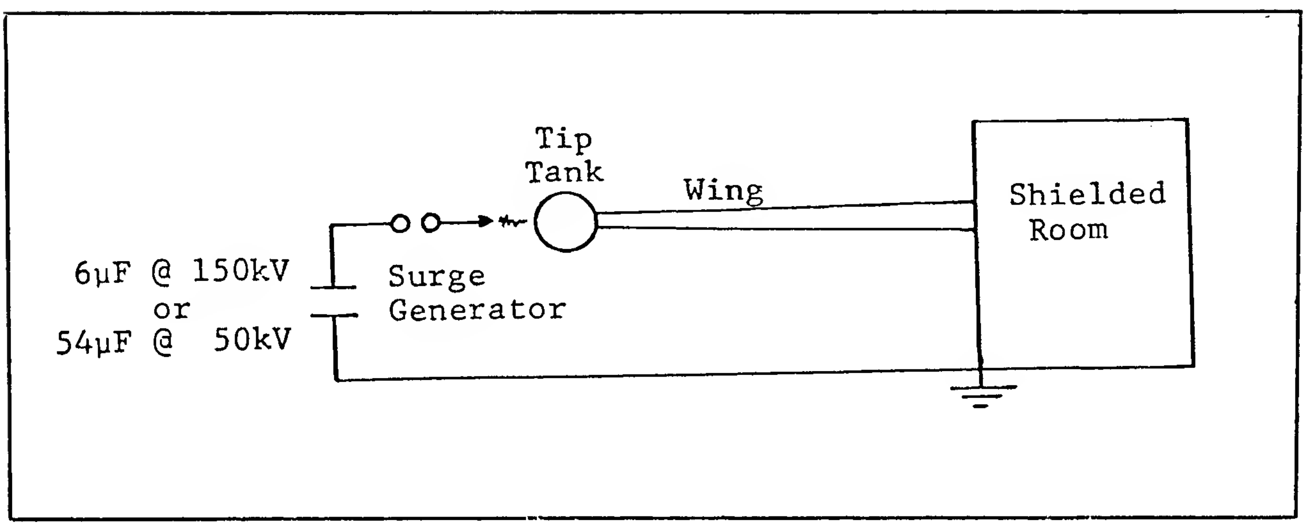

Tip
Tank
Wing
Shielded
Room
6μF @ 150kV
or
54μF @ 50kV
Surge
Generator

EXHIBIT B-12

This last test also produced some unexpected results in the tip tank electrical wiring. Doug recalled, "When the lightning strike hit the tank, it immediately attempted to dissipate the current into the two spars and three fuel lines. The electrical wires for the navigation lights and strobe lights in the tip tank were positioned parallel to the spars and fuel lines. As the current flowed in the spars and fuel lines, it set up a magnetic field which the wires cut through. The magnetic field induced a voltage in the wiring which was on the order of 1853 volts compared to the normal 28 volts in the circuit. We felt this was too high to tolerate." The electrical engineers at Beech decided to shield the wiring with a metal conduit which was fabricated from aluminum tubing.

Both the plastic tube support bracket and the electrical conduit were shipped to General Electric for final testing. Doug said, "We were confident these two changes would solve our problem but it was important to retest and verify the design." The test was conducted and the new designs proved to be the solution to both lightning strike problems.

This was the conclusion to the design and testing stage of building the wing tip tanks for the Model 200 aircraft. The last job was to complete any final FAA certification data which had not been previously submitted. Doug stated, "We maintain a FAA Certification file at Beech which is a complete listing of all changes and modifications to our aircraft. The file is physically located at Beech but has the same meaning as if it were located in the offices of the FAA at Mid-Continent Airport in Wichita. We write letters to the file and give a complete breakdown on how we complied with each applicable FAA requirement. These requirements were discussed and agreed upon at the very beginning of the program. No program of this magnitude can be initiated until all the rules of the game are first decided on."

"In retrospect," Doug continued, "this program was a good example of how most of our engineering jobs at Beech are conducted. If the job is much larger, such as designing, building and certifying an entirely new airplane, the program is more complex and more people are involved. But you still take the same basic steps, namely:

1. Customer/Beech provides design criteria to meet
2. Proposed solution(s) are presented
3. Negotiated solution is selected
4. FAA certification rules are formally agreed upon
5. Prototype part is built
6. Prototype part is tested and evaluated
7. Prototype part construction and test results are documented and FAA certified
8. Production parts are built

All these steps are necessary but do not always occur in the order shown. Many times production parts start while testing is going on to save time."

Doug said he felt this particular job gave him insight into the workings of the whole company because he saw the program beginning at a very early stage. "I have a friend in the Marketing Department," Doug recalled, "who kept me informed on how this program was advancing in the early stages long before the full Engineering Department would normally be involved. It was exciting to see an idea grow into a full fledged program and actually design, build and test the idea. For me, real engineering is being involved in the complete cycle from idea to hardware. The only link missing at this time is feedback from the field telling me how well the system is functioning. But that will come with time and when it does, it will be a continuation of what has already been learned."

"I learned several things on this project," Doug continued. "First, the vendor coordination with Globe Engineering was new to me in that I went to their facilities to coordinate on production of the tanks. I work with our shop all the time, but an outside production shop provided me with new insight into the workings of our own Quality Control Department. Several times I was called upon to help solve problems in reworking tanks rejected by our Quality Control Department. This was necessary in order to maintain delivery of parts on schedule. I was able to see the many inspection steps and procedures required before a piece of equipment is judged satisfactory for use on our aircraft."

Doug and Gene both became more involved directly in the testing of the tip tanks than in previous programs. This was the first time either of them had monitored a test so closely. This turned out to be important because when the different failures in the tank occurred, they had first hand knowledge of what actually happened. "I was particularly interested in the analysis of each failure," Doug stated. "To look at the failed parts and try to reconstruct in your mind the events leading up to the failure was a real challenge. But most of all, the failure analysis provided knowledge to be used in the design of future hardware."

The third area of the program which provided new design experience was in the design and testing for lightning protection. "My knowledge of lightning phenomena was very limited before this program started," Doug related. "The several days research I did in the Beech Library taught me a lot about conditions which create lightning, how it strikes, the energy levels in an average strike and how to protect aircraft structures from damage. The information I learned was applicable anywhere on an airplane and not just on tip tanks." Doug was particularly impressed by lightning tests at General Electric. "Obviously you can't just sit around waiting for a rainy day to run a lightning test," Doug said. "You have to be able to make your own lightning and, most of all, control it! Watching the test and seeing the results builds plenty of respect for the energy released by lightning."

Doug also pointed out that the process of writing the case study was beneficial. "It has given me the opportunity to look back at one particular program in detail and examine the events one by one. This is the first time I have had the opportunity to study each of the steps in the design process and think about what was learned during each phase. In the day-to-day routine job you run into a problem, overcome it, and go on to the next problem, usually with not much thought as to what was learned."

"I also believe this report has helped me to better understand how Beech Aircraft is organized and how it functions. Until now I had a rather narrow view of how programs were put together and carried to completion. This report gave me better insight into how many departments work together. I began to see that Engineering was the middle link in the chain with the Sales and Marketing Department at the front and Manufacturing at the end. All three units are required to complete a given task."

Instructors Note
for
Tip Tanks for the Beech
Super King Air

This case study was written for undergraduate students majoring in Engineering. It is intended to provide the student with insight into how a sample project begins, how the design develops and, finally, how the hardware and system is tested. This case study examines the structure of an Engineering Department within a typical aircraft company. Organization of the particular project is discussed and areas of responsibility are pointed out to the student. The design procedures in one particular project group are followed from start to finish. Specific examples of engineering decisions are presented showing that no clear-cut answer is available in most cases. Trade-offs in optimum performance must be made to obtain a product acceptable to everyone concerned.

A section of this case study is devoted to an engineering job not usually discussed in the typical engineering curriculum: determining the cost of the project. The case study example looks at the engineer's job of determining how much the project will cost before it is started. A sample job breakdown is provided with the hours bid to do the described job left blank. This could provide a possible problem for the student to attempt. The actual hours bid for the example project are shown on the next page.

The second part of the case study deals with the hardware and system testing that were performed on the finished product. Details of unanticipated problems are given and how solutions are found. The student can see that engineering design projects rarely run smoothly and problems should be expected to occur.

Model 200 52-Gallon Tip Tank Job Bid

Task	Percent of Total Hours*
1. Design a separate wing tip tank fuel system installation drawing (2 J-size sheets). Drawing shall show all fuel and vent lines up to but not including equipment installation on end of integral fuel tank. Drawing shall show installation of flapper valves, drain valves, anti-siphon valve and electrical connector for fuel quantity probes.	14.4%
a. Design an access plate for fuel vents and electrical plug to pass through wall of tank. (One D-size drawing)	2.3
2. Add a tabulation to 101-920000 to allow incorporation of tank assembly into main fuel system. (One E-size layout and two C.O.'s - change order)	6.6
a. Design adapter plate for outboard end of integral tank.	2.3
b. Create new fuel gauging drawing to add new fuel quantity probes to tip tank. One C.O. and D-size layout.	2.0
3. Calibrate tip tank fuel quantity indicating system.	3.9
4. Engineering coordination with:	
a. Globe Engineering	10.0
b. Project Group	2.7
c. Electrical Engineering Group	2.2
d. Rochester Gauges, Inc.	1.6
e. Experimental Shop (Fabrication and installation of plumbing and hardware)	5.0
f. Flight Test Group	4.4
g. Publications (Flight Manual and Maintenance Manual)	2.2
h. General Electric for lightning test.	4.4
5. Supervision.	12.7
6. Design of the tip tank structure. This includes fuel plumbing, navigation lights installation, mounting brackets and lightning protection for the tank. Project Group will design tank fairings. 5 E-size drawings.	17.8
7. Interpretation and analysis of ground and flight test data.	2.2
8. Preparation of FAA certification letters and documents.	3.3
Total	100.0%

*Actual hours deleted at company request.